# The RR Lyrae Distance to the Draco Dwarf Spheroidal Galaxy

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## ABSTRACT

We present the first CCD variability study of the Draco dwarf spheroidal galaxy. The data were obtained with the FLWO 1.2 m telescope on 22 nights, over a period of 10 months, covering a $22' \times 22'$ field centered at $\alpha = 17:19:57.5, \delta = 57:50:05$, J2000.0. The analysis of the $BVI$ images produced 163 variable stars, 146 of which were RR Lyrae: 123 RRab, 16 RRc, 6 RRd and one RR12. The other variables include a SX Phe star, four anomalous Cepheids and a field eclipsing binary. Using the short distance scale statistical parallax calibration of Gould & Popowski and 94 RRab stars from our field, we obtain a distance modulus of $(\mathrm{m}-\mathrm{M})_0 = 19.40 \pm 0.02\,(\mathrm{stat}) \pm 0.15\,(\mathrm{syst})$ mag for Draco, corresponding to a distance of 75.8 $\pm 0.7\,(\mathrm{stat}) \pm 5.4\,(\mathrm{syst})$ kpc. By comparing the spread in magnitudes of RRab stars in $B, V$ and $I$, we find no evidence for internal dust in the Draco dwarf spheroidal galaxy.

The catalog of all variables, as well as their photometry and finding charts, is available electronically via `anonymous ftp` and the `World Wide Web`. The complete set of the CCD frames is available upon request.

*Subject headings:* Local Group — distance scale — galaxies: dwarf — galaxies: individual (Draco dSph, UGC 10822)

## 1. Introduction

Dwarf spheroidal (dSph) galaxies are probably the most common types of galaxies in the present-day Universe. They are metal poor galaxies with a metallicity $Z < 0.001$ (Mateo 1998), which resembles that found in galactic globular clusters. Most dSph galaxies show evidence for multiple star-formation episodes, having populations of different ages. There

are very few, namely Tucana, Draco and possibly Ursa Minor, that host a single stellar population older than 10 Gyr (see Dall'Ora et al. 2003, and references therein).

The Draco dSph galaxy, a companion to the Milky Way, was discovered by Wilson (1955) and was first observed by Baade & Swope (1961) for variables. They found 261 variables in their $24' \times 24'$ field, but only measured 137 for magnitudes. Of these, 133 were RR Lyrae variables, which they used to derive the distance to the galaxy. There have not been any recent variability studies of Draco, except for the survey by Kinemuchi et al. (2002) which is currently underway. The lack of high quality CCD observations of the RR Lyrae in Draco dSph motivated us to do this project.

However, several studies of Draco's stellar population have been conducted and for these CCD photometry has been obtained. Grillmair et al. (1998) present the CMD diagram obtained from observations with the *Hubble Space Telescope (HST)* and confirm that star formation in Draco was primarily single-epoch and that Draco is very similar to the globular clusters M68 and M92, but 1.6 Gyr older. It has a luminosity of $2 \times 10^5\,L_\odot$, which places it among the least luminous galaxies known. Bellazzini et al. (2002) have done a comparative study of the Draco and Ursa Minor dSph galaxies with new $V, I$ photometry. Recently, Rave et al. (2003) have released a catalog of photometry of $\sim 5,600$ stars in Draco. They find 142 candidate variables from their colors, using photometry from five catalogs. However, a uniform dataset taken with the same instrument would be more reliable for finding RR Lyrae and obtaining accurate photometry and periods for them.

In this paper, we present a catalog of variable stars found in Draco dSph. The paper is organized as follows: §2 provides a description of the observations; the data reduction procedure, calibration and astrometry is outlined in §3; the catalog of variable stars is presented in §4. In §5 we determine the distance to Draco and in §6 we summarize our results.

## 2. Observations

The observations of the Draco dSph were made with the 1.2m telescope at the Fred Lawrence Whipple Observatory on Mount Hopkins, Arizona, between August 19th, 1998 and June 20th, 1999, over 22 nights. We used the "4Shooter" camera (Szentgyorgyi et al. 2003), with 4 thinned and AR-coated Loral $2048^2$ pixel CCDs. The pixels are 15 microns in size and map to $0.33''$ per pixel on the focal plane, making each image $11'$ on the side. The camera was centered at $\alpha = 17{:}19{:}57.5, \delta = 57{:}50{:}05$, J2000.0. The data consists of $148 \times 600$ $s$ exposures in the $V$ filter, $44 \times 900$ $s$ exposures in the $B$ filter and $47 \times 600$ $s$ exposures in

the $I$ filter. The median value of the seeing in $V$ was $2.0''$. The field was observed through airmasses ranging from 1.12 to 1.55, with the median being 1.19. The completeness of our photometry starts to drop rapidly at about 22.5 in $I$ and 23 mag in $V$ and $B$. The CCDs saturate for stars brighter than 14 in $I$, 15 in $V$ and 15.5 mag in $B$. On one photometric night of the run, several images of standard Landolt (1992) fields were taken.

## 3. Data Reduction, Calibration and Astrometry

Preliminary processing of the data was performed with standard routines in the IRAF [1] CCDPROC package. The differential photometry for the variable stars was extracted using the ISIS image subtraction package (Alard & Lupton 1998; Alard 2000) from the $V$-band data. The DAOPHOT/ALLSTAR package (Stetson 1987) was used for the conversion into magnitudes. Mochejska et al. (2001) describe the procedure in detail.

On August 31st, 1998, we observed 2 sets of 3 Landolt (1992) fields in the $BVI$ filters at air masses ranging from 1.18 to 1.99. The transformation from the instrumental to the standard system was derived for each chip in the following form:

$$
\begin{aligned}
b &= B + \chi_{\rm b} + \xi_{\rm b} \cdot ({\rm B-V}) + \kappa_{\rm b} \cdot {\rm X} \\
v &= V + \chi_{\rm v1} + \xi_{\rm v1} \cdot ({\rm B-V}) + \kappa_{\rm v1} \cdot {\rm X} \\
v &= V + \chi_{\rm v2} + \xi_{\rm v2} \cdot ({\rm V-I}) + \kappa_{\rm v2} \cdot {\rm X} \\
i &= I + \chi_{\rm i} + \xi_{\rm i} \cdot ({\rm V-I}) + \kappa_{\rm i} \cdot {\rm X}
\end{aligned}
$$

where lowercase letters correspond to the instrumental magnitudes, uppercase letters to standard magnitudes, X is the airmass, $\chi$ is the zeropoint, $\xi$ the color and $\kappa$ the airmass coefficient. Since most of the color coefficients are small, we used $B-V = V-I = 1$ when transforming the magnitudes of our stars. Note that the $B$-band coefficients are larger, therefore our B magnitudes for red stars may be off by 0.1 mag or 0.2 mag (in chip 2), in the worst case.

Stetson (2000) has calibrated $\sim$ 400 stars in the Draco dSph as secondary standards. In chips 3 and 4, where our overlap was large, we normalized to his photometry using the

[1]IRAF is distributed by the National Optical Astronomy Observatories, which are operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the NSF.

brightest 80 stars (to 19.5 mag) and 66 stars (to 20th mag) respectively to determine the offsets in $V$. The difference between his photometry and ours in these chips was 0.04 and 0.02 mag. In chips 1 and 2 the overlap was too small for a meaningful comparison, thus we kept our own photometry. We then compared our normalized $V$ photometry in chips 3 and 4 with the photometry of Grillmair et al. (1998) from the *HST*. For 100 stars down to 19 mag, the differences between their photometry and ours were 0.06 and 0.03 mag. Bellazzini et al. (2002) have obtained $(V, I)$ photometry of the field and the agreement with our photometry is good, the largest offset being 0.07 mag in chip 3, $V$-band.

Equatorial coordinates were determined for the $V$ star list. The transformation from rectangular to equatorial coordinates was derived using for chips 1-4: 174, 146, 400 and 282 transformation stars respectively with $V < 20$ from the USNO-A2.0 (Monet 1996) catalog. The median difference between the catalog and the computed coordinates for the transformation stars was $0.''3$ in RA and $0.''3$ in Dec. We also compared the astrometry to Stetson's catalog and found 18, 4, 272 and 151 matches for chips 1-4, having a median offset $< 0.''2$. We use these derived J2000.0 equatorial coordinates to name the variables in the format: Draco*hhmmss.s*+*ddmmss.s*. The first three fields (*hhmmss.s*) correspond to RA expressed in hours, the last three (*ddmmss.s*) to Dec, expressed in degrees, separated by the declination sign.

## 4. Results

Our search for variables in our field in Draco produced 163 stars, 136 of which were previously identified by Baade & Swope (1961). The remaining 27 are new discoveries. Of these 163 stars, 146 are RR Lyrae, 4 are anomalous Cepheids and the remaining 13 are other long period or non-periodic variables. We found a new field eclipsing binary and a SX Phe star among these. Of the 146 RR Lyrae, 123 are fundamental mode pulsators (RRab), 16 are first overtone pulsators (RRc), 6 are double-mode pulsators (RRd) and one is pulsating in the first and second overtone (RR12). Figures 1, 2 and 3 show typical light curves of RR Lyrae and other variables found in Draco. Tables 1 and 2 present coordinates, periods, intensity averaged $BVI$ magnitudes, $V$-band amplitudes, the type of variable and the corresponding name given in Baade & Swope (1961). Stars exhibiting the Blazhko effect are also marked. The catalog of all variables, as well as their $BVI$ photometry and $V$ finding charts, is available electronically via `anonymous ftp`[2] and the `World Wide Web`[3]. The complete set of

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[2]On `cfa-ftp.harvard.edu`, in `pub/kstanek/DIRECT/Draco`

[3]`http://cfa-www.harvard.edu/~kstanek/DIRECT/Draco`

the CCD frames is available upon request.

We used the multiharmonic analysis of variance technique (Schwarzenberg-Czerny 1996) to search the light curves for periodicity. Additionally, Fourier series were fit to the RR Lyrae light curves phased to the period determined earlier and parameters such as the amplitude of the variation and amplitude and phase of each harmonic were calculated. We searched for multiperiod variables by subtracting the first three harmonics of the Fourier series from the phased light curves and then repeating the period search. We then redetermined secondary periods for the 6 double mode (RRd) stars found by Nemec (1985) in the data of Baade & Swope (1961), by searching the periodogram where the second period was expected.

Baade & Swope (1961) do not find any red irregular or long period variables in their data, with the exception of BS-203, a bright blue variable with a period of $\sim 3$ years. We observed all of their "special variables" except for BS-138. The only significant difference in these is that the period we find for BS-134 is 0.592 days, not 1.458 days, which agrees with Nemec (1985) who realanyzed the data of Baade & Swope (1961). The periods we calculated for variables also found by Baade & Swope (1961) are very similar in most cases. The cases that differ are marked with an asterisk in Table 1. As a result some stars are classified differently from Baade & Swope (1961). BS-97, BS-121, BS-173 and BS-145 are all RRc stars and BS-190, BS-169, BS-143, BS-72, BS-11, BS-112 are RRd stars. We did not find variables BS-10, BS-31, BS-111 and BS-195 due to the proximity of highly saturated stars.

We present a histogram of the 139 RRab and RRc Lyrae in Draco, with 0.02 day bins in Figure 4. Both components of the double-mode stars are also plotted (in black). The median period for RRab stars is 0.617 days and for RRc stars is 0.392 days, which places the Draco dSph between Oosterhoff type I ($\sim 0.55$ days) and type II ($\sim 0.65$ days) clusters, similarly to other dSph (Dall'Ora et al. 2003). In Figure 5 we present a color magnitude diagram (CMD) of stars in Draco. Circles represent RR Lyrae, squares are anomalous Cepheids and triangles are other variables. Among these other variables is the long period blue variable BS-203, a foreground 0.24 day eclipsing binary, and a multimode SX Phe star which is pulsating in three modes, with periods 0.068, 0.073 and 0.079 days. The period-amplitude diagram for the 146 RR Lyrae in Draco is shown in Figure 6. Circles represent RRab stars, triangles RRc stars and squares RRd stars, for which both periods are plotted.

## 5. Distance to Draco dSph

The distance to the Draco dSph galaxy has been estimated by several authors. Baade & Swope (1961) obtained a distance of $d = 99$ kpc assuming an absolute magnitude of $M_B = 0.5$ mag for RR Lyrae; Nemec (1985) obtained $d = 84 \pm 12$ kpc using RRd stars found by reanalyzing the data of Baade & Swope (1961); Aparicio et al. (2001) obtained $d = 80 \pm 7$ kpc by the magnitude of the horizontal branch at the RR Lyrae instability strip; Bellazzini et al. (2002) obtained $d = 92.9 \pm 6$ kpc by fitting template cluster horizontal branches.

We use the short distance scale statistical parallax calibration of Gould & Popowski (1998), which is a robust method of measuring the absolute magnitude of RR Lyrae stars. They find

$$\mathrm{M_V} = 0.77 \pm 0.13, \tag{1}$$

at $\langle[\mathrm{Fe/H}]\rangle = -1.60$, for a sample of 147 halo RR Lyrae stars with high-quality proper motions from the *Hipparcos* (European Space Agency 1997) and Lick NPM1 (Klemola, Hanson & Jones 1993) surveys. Shetrone et al. (2001) find $\langle[\mathrm{Fe/H}]\rangle = -2.00 \pm 0.21$ in Draco dSph from high resolution spectroscopy of 6 red giants in the galaxy. Lehnert et al. (1992) also found a metallicity of $\langle[\mathrm{Fe/H}]\rangle = -1.9$, $\sigma = 0.4$, from spectra of 14 giants. The abundances seem to fall into two groups, one with an average [Ca, Mg/H] near $-1.6 \pm 0.2$ and the other $-2.3 \pm 0.2$. We adopt the value $\langle[\mathrm{Fe/H}]\rangle = -2.00$ (also quoted in Mateo 1998) for our distance determination. The metallicity correction is derived from the slope of the luminosity-metallicity relation for RR Lyrae, which lies between 0.2 (Chaboyer 1999) and 0.3 (Sandage 1993). Using 0.2 for the value of the slope and 0.4 dex for the difference in metallicity of Draco dSph from galactic RR Lyrae, we find $M_V = 0.69$ for the RR Lyrae in Draco dSph.

Draco dSph is located at Galactic coordinates $l = 86\overset{\circ}{.}37, b = 34\overset{\circ}{.}72$. To remove the effects of the Galactic interstellar extinction we used the reddening map of Schlegel et al. (1998) which yields $E(B-V) = 0.027$ mag. This corresponds to expected values of Galactic extinction of $A_I = 0.053$, $A_V = 0.091$, $A_B = 0.118$ mag, using the extinction corrections of Cardelli et al. (1989) as prescribed in Schlegel et al. (1998).

For the distance determination we only used the RRab stars found in chips 3 and 4, which are normalized to the photometry of Stetson (2000). There are 94 such stars in our data. The remaining RRab stars from chip 1 and 2 are not included in this list. We fit a Gaussian to a histogram of these 94 stars, using 0.03 mag bins and found $\langle \mathrm{m_V} \rangle = 20.18 \pm 0.02$, $\sigma = 0.08$, as shown in Figure 7. This value is in agreement with the value of Aparicio et

al. (2001) for the horizontal branch at the RR Lyrae instability strip, $20.2 \pm 0.1$ mag, and with the value of Bellazzini et al. (2002) of $20.30 \pm 0.12$ mag, obtained by fitting to the template cluster M68. Our measurement implies a distance modulus of $\mathrm{m_V} - \mathrm{M_V} = 19.49$ mag. Correcting for extinction gives a true distance modulus of $(\mathrm{m}-\mathrm{M})_0 = 19.40$ mag and a distance of 75.8 kpc to Draco dSph.

The systematic errors are 0.06 mag in $A_V$, 0.03 mag in photometry, 0.13 mag in the calibration method and 0.04 mag in metallicity. The error in the reddening from Schlegel et al. (1998) is 0.02 mag, which corresponds to 0.06 mag in $A_V$, and the error in metallicity is calculated from a conservative error of 0.1 in the slope of the luminosity-metallicity relation times 0.4 dex, the metallicity difference. Adding the systematic errors in quadrature gives a conservative total estimate of 0.15 mag, which is dominated by the calibration error. We consider the effects of internal extinction to be negligible from a comparison of the spread in magnitudes of RRab stars in different filters. Similarly to Figure 7 for $V$ with $\sigma = 0.08$, the spread in magnitudes of RRab stars in $B$ and $I$ are $\sigma = 0.10$ and 0.12, respectively. Thus we find no evidence for internal dust in the Draco dSph galaxy.

The statistical error is 0.02 mag, which leads to a true distance modulus of $(\mathrm{m}-\mathrm{M})_0 = 19.40 \pm 0.02\,(\mathrm{stat}) \pm 0.15\,(\mathrm{syst})$ mag, corresponding to a distance of $75.8 \pm 0.7\,(\mathrm{stat}) \pm 5.4\,(\mathrm{syst})$ kpc.

## 6. Conclusions

We have presented the results of the first CCD variability study in the Draco dSph galaxy since Baade & Swope (1961). Our search produced 163 variable stars, 146 of which are RR Lyrae, 4 are anomalous Cepheids, 1 is a field eclipsing binary, 1 a SX Phe star and 11 are other types of variables. We have used the short distance scale statistical parallax calibration of Gould & Popowski (1998) for 94 RRab in our field and obtained a distance modulus of $(\mathrm{m}-\mathrm{M})_0 = 19.40 \pm 0.02\,(\mathrm{stat}) \pm 0.15\,(\mathrm{syst})$ mag. By comparing the spread in magnitudes of RRab stars in different filters, we find no evidence for internal dust in the Draco dSph galaxy.

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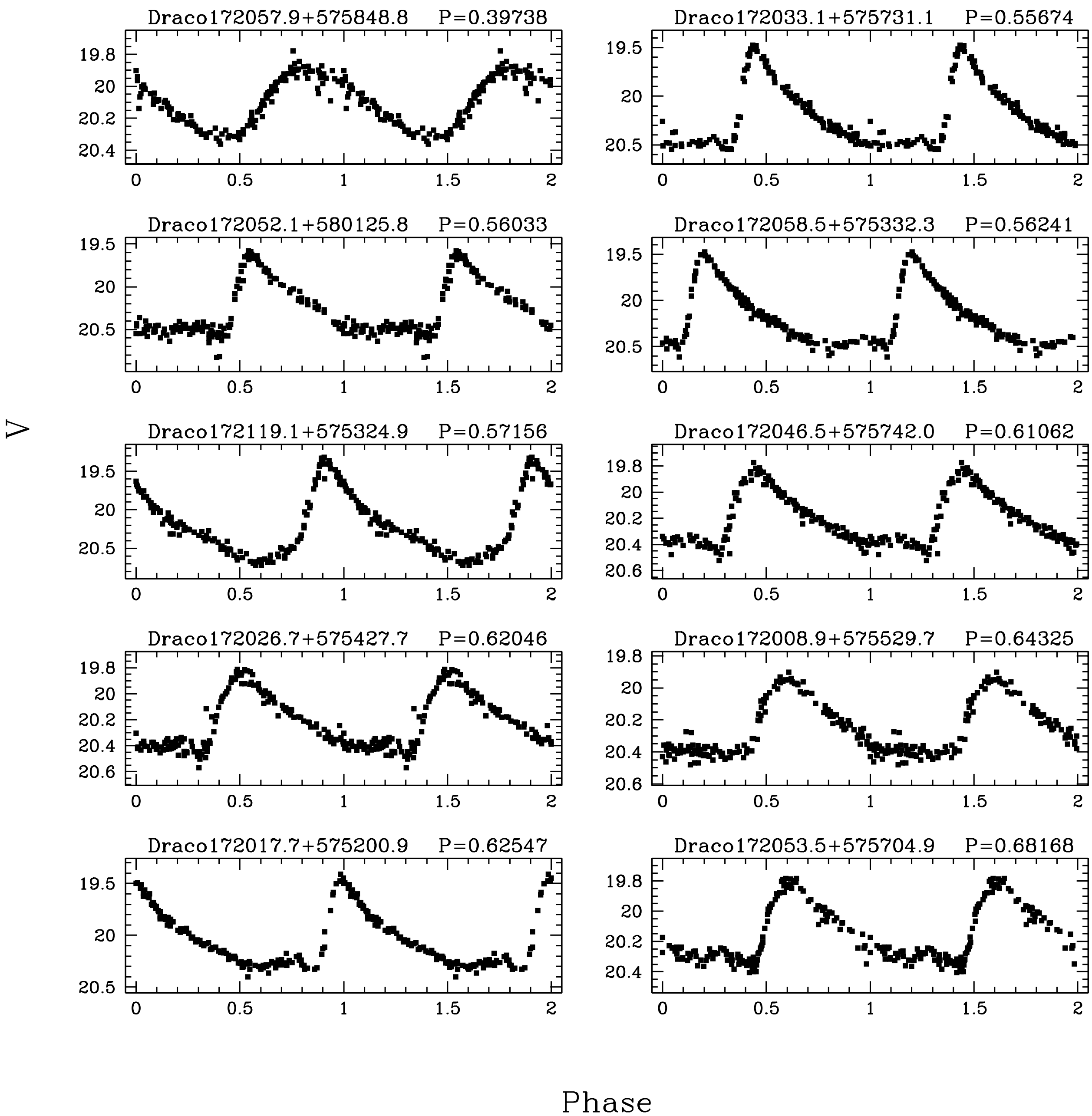


Fig. 1.— Sample light curves of RR Lyrae variables found in Draco dSph, representing typical quality data over a range of periods.

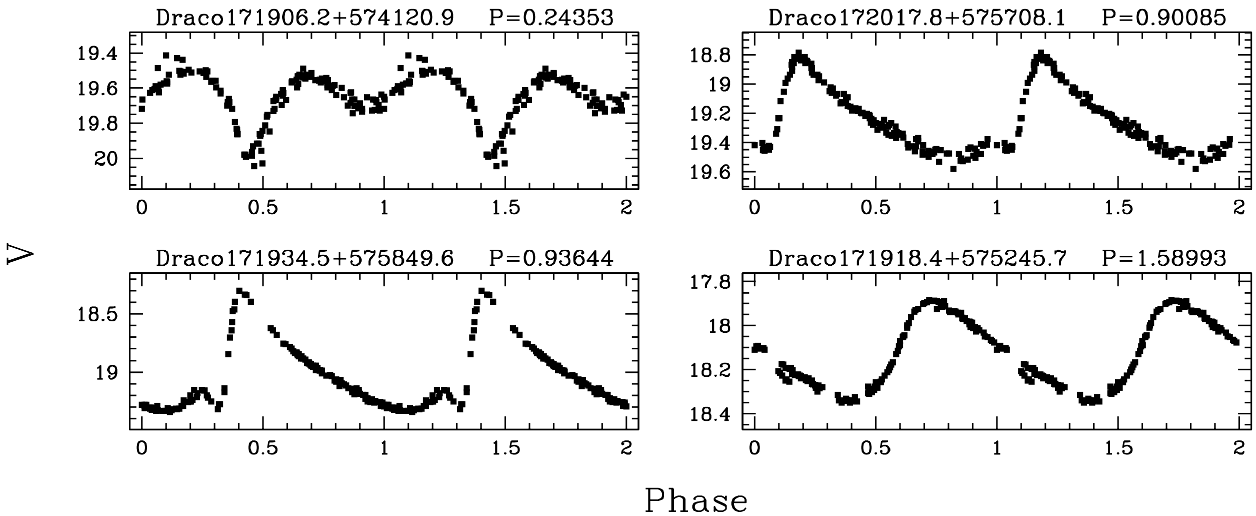


Fig. 2.— Light curves of selected other periodic variables found in Draco dSph. An eclipsing binary and 3 anomalous Cepheids are shown.

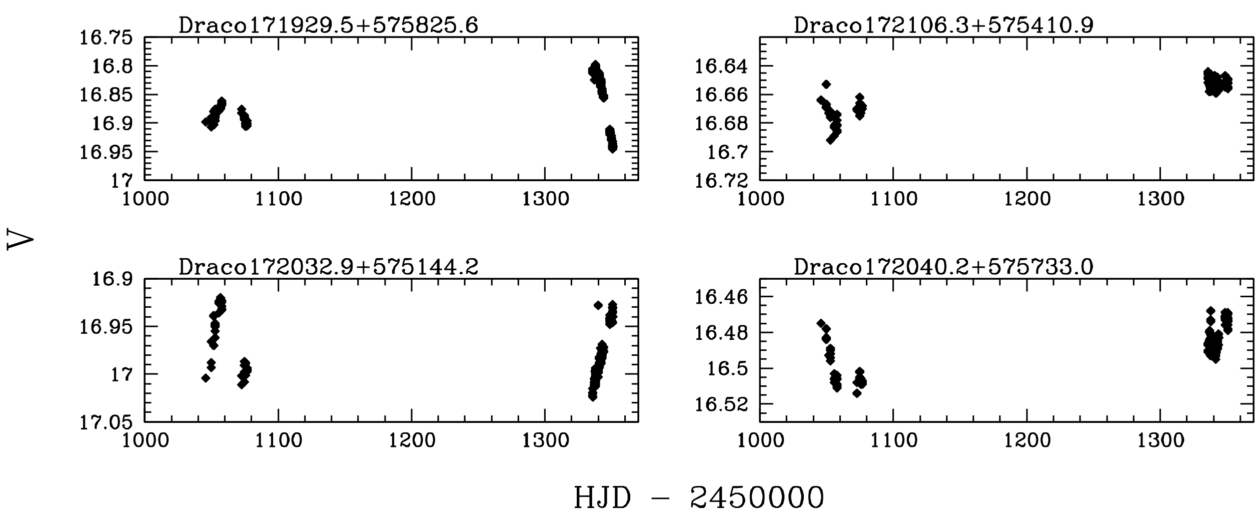


Fig. 3.— Sample light curves of other variables found in Draco dSph.

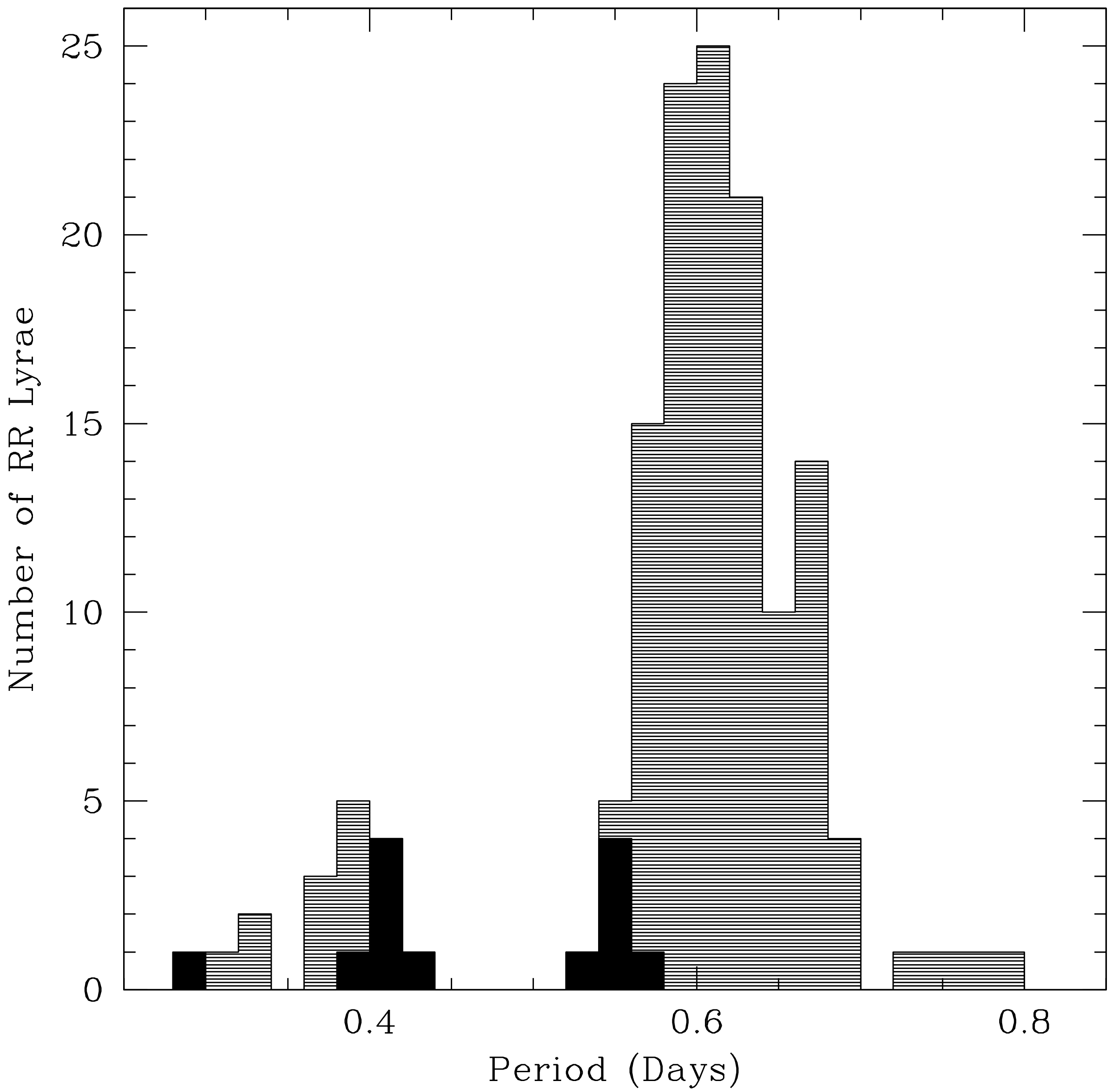


Fig. 4.— Period distribution of 146 RR Lyrae in Draco. The median period for RRab stars is 0.617 and for RRc stars 0.392. Both components of the double-mode stars are also plotted in black.

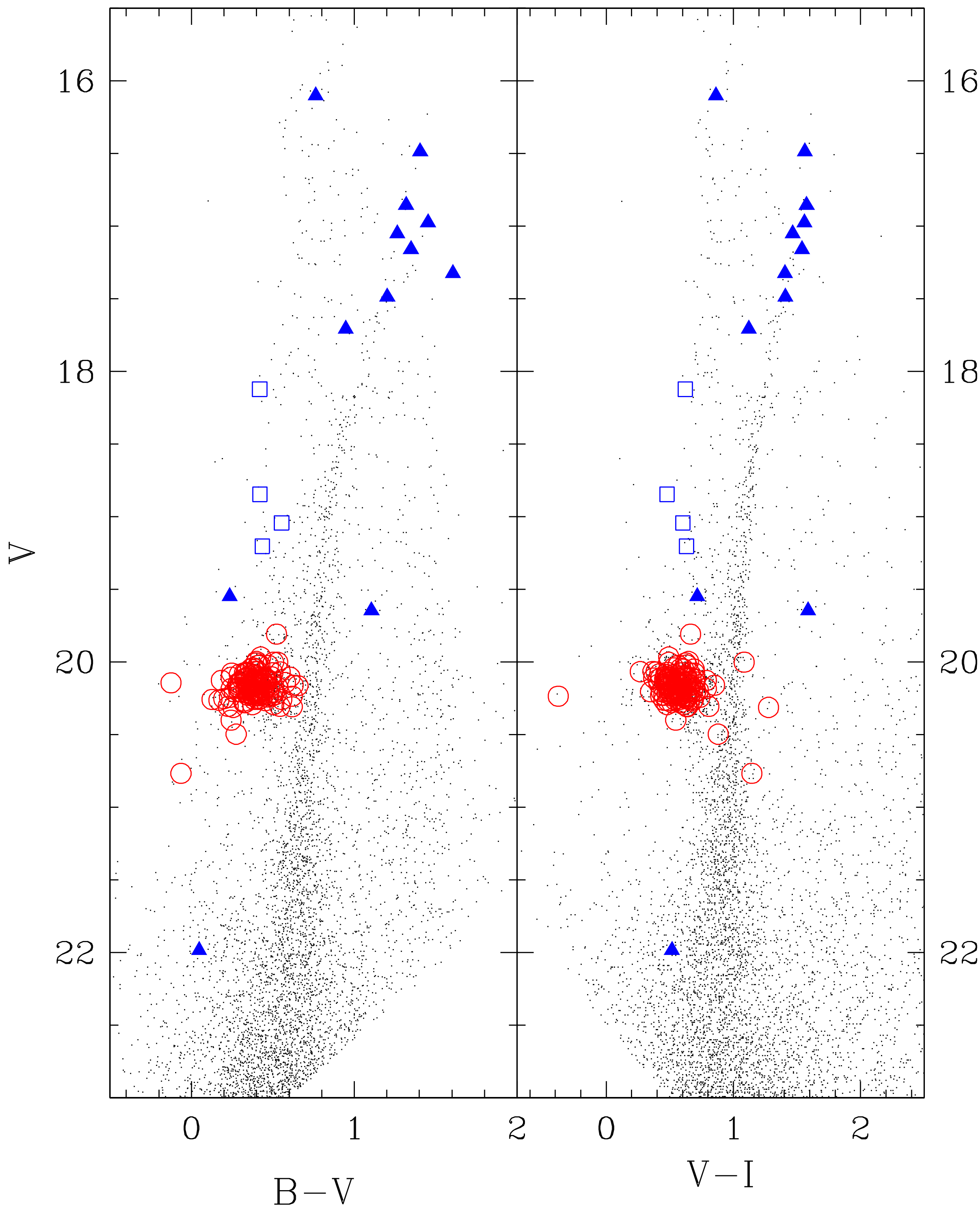


Fig. 5.— CMD for variables and nonvariable stars. Circles represent RR Lyrae, squares are anomalous Cepheids and triangles are other variables.

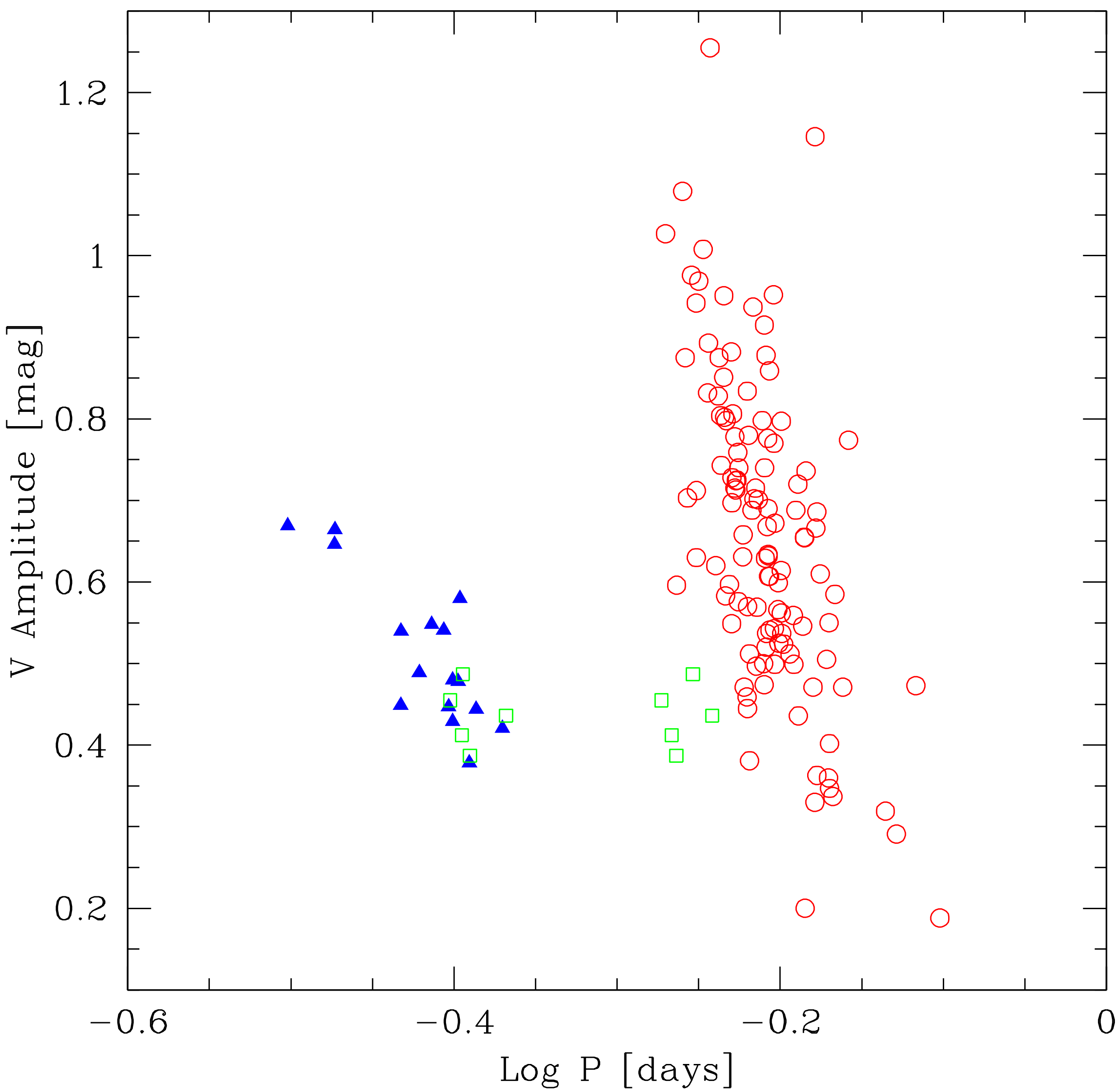


Fig. 6.— Period-amplitude relation for 146 RR Lyrae in Draco dSph. Circles represent RRab stars, triangles RRc stars and squares RRd stars, for which both periods are plotted.

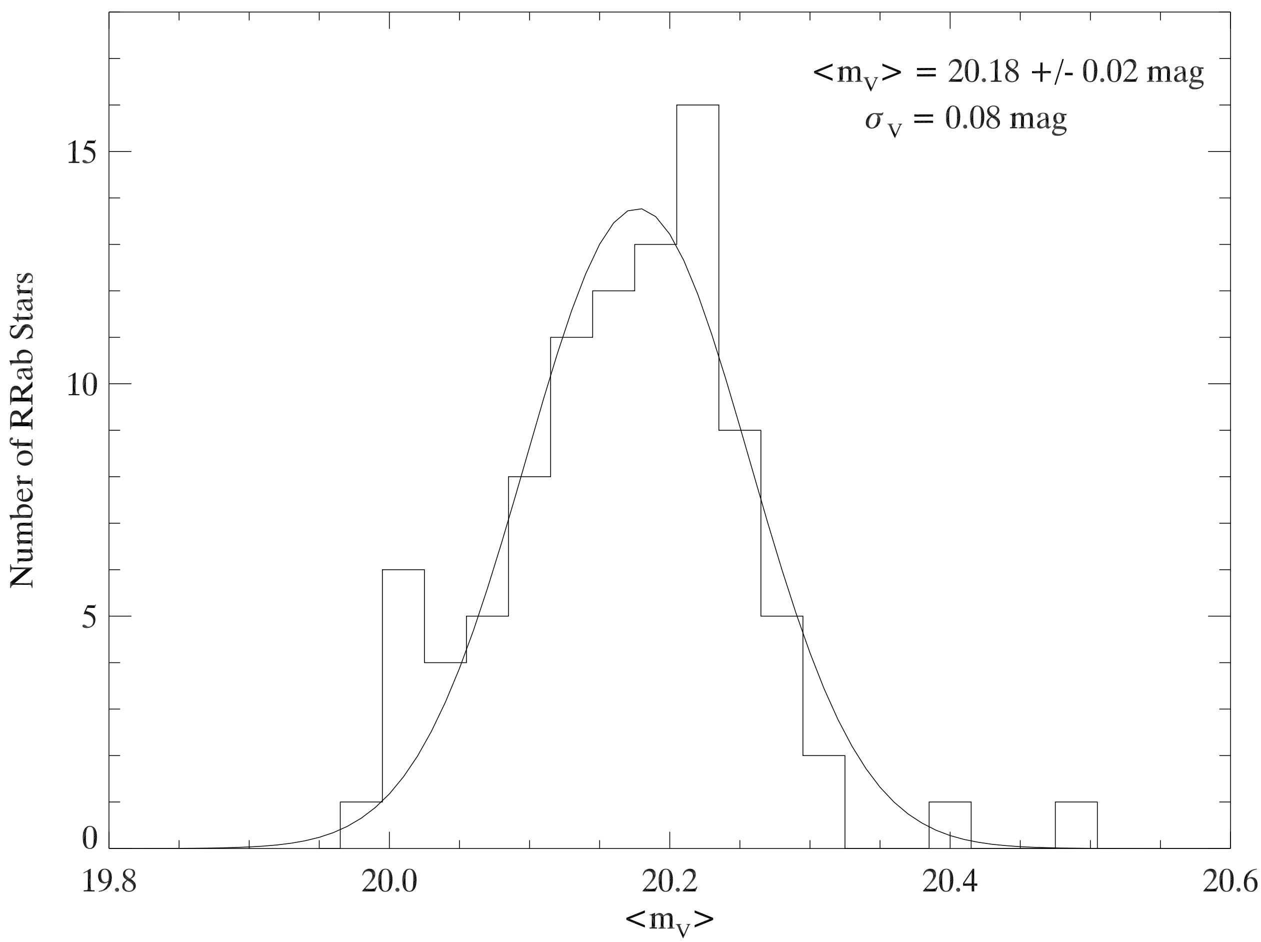


Fig. 7.— Histogram of 94 RRab magnitudes and the Gaussian fit, centered at $\langle m_V \rangle = 20.18 \pm 0.02$ mag.

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Table 1. RR Lyrae in Draco Dwarf Galaxy

| Name | $P$ (*days*) | $\langle V \rangle$ (mag) | $\langle I \rangle$ (mag) | $\langle B \rangle$ (mag) | $Amp_V$ (mag) | Type | Comments[a] |
|---|---|---|---|---|---|---|---|
| Draco172052.0+575532.4 | 0.28767$^{\dagger}$ | 20.205 | 19.855 | 20.496 | 0.356 | RR12 | BS-170 |
| ··· | 0.40431 | ··· | ··· | ··· | ··· | ··· | ··· |
| Draco172059.1+580006.0 | 0.31478* | 20.263 | 19.808 | 20.432 | 0.669 | c | BS-97 |
| Draco171936.4+574930.0 | 0.33633 | 20.230 | 19.802 | 20.627 | 0.646 | c | BS-46 |
| Draco171936.1+575415.8 | 0.33646* | 20.081 | 19.659 | 20.417 | 0.664 | c | BS-121 |
| Draco171908.1+575835.0 | 0.36924$^{\dagger}$ | 20.204 | 19.769 | 20.576 | 0.449 | c | BS-110 |
| Draco172059.5+575542.7 | 0.36947* | 20.151 | 19.735 | 20.517 | 0.540 | c | BS-173 |
| Draco171938.4+574724.7 | 0.37903$^{\dagger}$ | 20.152 | 19.683 | 20.570 | 0.489 | c | BS-50 |
| Draco172112.7+580131.2 | 0.38572$^{\dagger}$ | 20.176 | 19.726 | 20.462 | 0.548 | c | BS-181 |
| Draco172110.8+574736.2 | 0.39233$^{\dagger}$ | 20.068 | 19.675 | 20.613 | 0.541 | c | BS-179 |
| Draco171917.5+580107.5 | 0.39502 | 20.145 | 19.671 | 20.433 | 0.447 | c | ··· |
| Draco172042.5+575153.5 | 0.39597* | 20.120 | 19.617 | 20.509 | 0.455 | d | BS-190 |
| ··· | 0.53351 | ··· | ··· | ··· | ··· | ··· | ··· |
| Draco171917.5+574843.0 | 0.39728$^{\dagger}$ | 20.120 | 19.640 | 20.580 | 0.480 | c | BS-191 |
| Draco172057.9+575848.8 | 0.39738* | 20.071 | 19.589 | 20.408 | 0.429 | c | BS-145 |
| Draco171942.4+575837.9 | 0.40049$^{\dagger}$ | 20.108 | 19.607 | 20.448 | 0.478 | c | BS-120 |
| Draco172017.5+574601.7 | 0.40155$^{\dagger}$ | 20.151 | 19.624 | 20.604 | 0.580 | c | BS-153 |
| Draco172042.3+575852.7 | 0.40258* | 20.126 | 19.591 | 20.310 | 0.412 | d | BS-169 |
| ··· | 0.54144 | ··· | ··· | ··· | ··· | ··· | ··· |
| Draco171942.5+575449.8 | 0.40319* | 20.129 | 19.594 | 20.519 | 0.487 | d | BS-143 |
| ··· | 0.55789 | ··· | ··· | ··· | ··· | ··· | ··· |
| Draco172119.5+575236.0 | 0.40685$^{\dagger}$ | 20.116 | 19.632 | 20.448 | 0.378 | c | BS-131 |
| Draco172012.4+575412.0 | 0.40720* | 20.105 | 19.614 | 20.710 | 0.387 | d | BS-72 |
| ··· | 0.54489 | ··· | ··· | ··· | ··· | ··· | ··· |
| Draco171930.5+575633.7 | 0.41080$^{\dagger}$ | 20.110 | 19.681 | 20.512 | 0.444 | c | BS-182 |
| Draco172041.9+575827.6 | 0.41215* | ··· | 19.616 | 20.310 | ··· | d | BS-11 |
| ··· | 0.55075 | ··· | ··· | ··· | ··· | ··· | ··· |
| Draco171907.8+574432.7 | 0.42626 | 20.122 | 19.635 | 20.510 | 0.421 | c | ··· |
| Draco172106.4+575153.4 | 0.42842* | 20.115 | 19.482 | 20.442 | 0.436 | d | BS-112 |
| ··· | 0.57322 | ··· | ··· | ··· | ··· | ··· | ··· |
| Draco172047.2+575759.7 | 0.53656 | 20.110 | 19.736 | 20.449 | 1.027 | ab | BS-13 |
| Draco172017.0+575240.2 | 0.54513 | 20.497 | 19.617 | 20.772 | 0.596 | ab,Bl? | BS-34 |
| Draco171919.5+575738.9 | 0.54967 | 20.280 | 19.700 | 20.604 | 1.079 | ab | BS-18 |
| Draco171923.3+575555.9 | 0.55185 | 20.002 | 18.917 | 20.506 | 0.875 | ab | ··· |
| Draco172008.4+575203.7 | 0.55345 | 20.181 | 19.653 | 20.474 | 0.703 | ab,Bl | BS-37 |
| Draco172033.1+575731.1 | 0.55674 | 20.156 | 19.664 | 20.441 | 0.976 | ab | BS-124 |
| Draco172052.1+580125.8 | 0.56033 | 20.212 | 19.698 | 20.573 | 0.942 | ab | BS-94 |

Table 1—Continued

| Name | $P$ ($days$) | $\langle V \rangle$ (mag) | $\langle I \rangle$ (mag) | $\langle B \rangle$ (mag) | $\mathrm{Amp_V}$ (mag) | Type | Comments[a] |
|---|---|---|---|---|---|---|---|
| Draco172058.9+575344.6 | 0.56055 | 20.266 | 19.783 | 20.720 | 0.630 | ab | BS-163 |
| Draco172032.5+575509.8 | 0.56062 | 20.244 | 19.508 | 20.477 | 0.712 | ab | BS-21 |
| Draco172049.8+575405.5 | 0.56174 | · · · | 19.530 | 20.615 | · · · | ab | BS-25 |
| Draco172058.5+575332.3 | 0.56241 | 20.119 | 19.660 | 20.546 | 0.969 | ab | BS-175 |
| Draco172042.5+573955.7 | 0.56600 | 20.142 | 19.597 | 20.719 | 1.008 | ab | · · · |
| Draco172016.7+575312.0 | 0.56917 | · · · | · · · | · · · | · · · | ab | BS-29 |
| Draco172015.2+575917.5 | 0.56957 | 20.195 | 19.663 | 20.532 | 0.832 | ab | BS-8 |
| Draco172020.5+580056.3 | 0.57011 | 20.252 | 19.625 | 20.451 | 0.893 | ab | BS-5 |
| Draco172119.1+575324.9 | 0.57156† | 20.067 | 19.799 | 20.459 | 1.255 | ab | BS-130 |
| Draco172038.4+575236.1 | 0.57603 | 20.270 | 19.593 | 20.592 | 0.620 | ab,Bl | BS-35 |
| Draco171927.1+574653.5 | 0.57631† | · · · | 19.693 | · · · | · · · | ab | BS-116 |
| Draco172041.9+575750.5 | 0.57642 | · · · | 19.732 | 20.572 | · · · | ab | BS-12 |
| Draco171926.6+575334.2 | 0.57804 | 20.279 | 19.764 | 20.610 | 0.828 | ab | BS-15 |
| Draco172042.9+575129.2 | 0.57877 | 20.219 | 19.683 | 20.573 | 0.875 | ab,Bl | BS-41 |
| Draco171934.1+575535.8 | 0.58002 | 20.107 | 19.562 | 20.508 | 0.804 | ab | BS-107 |
| Draco171941.4+575327.6 | 0.58048† | 20.249 | 19.691 | · · · | 0.743 | ab | BS-22 |
| Draco171939.1+575803.9 | 0.58258† | 20.160 | 19.568 | 20.606 | 0.851 | ab | BS-102 |
| Draco171949.9+574904.5 | 0.58273 | 20.101 | 19.633 | 20.592 | 0.951 | ab | BS-48 |
| Draco171935.7+575832.2 | 0.58332† | 20.206 | 19.571 | 20.623 | 0.802 | ab | BS-76 |
| Draco172103.5+575950.9 | 0.58410 | 20.124 | 19.653 | 20.508 | 0.583 | ab,Bl | BS-96 |
| Draco171948.2+575451.6 | 0.58468† | 20.253 | 19.622 | 20.674 | 0.798 | ab | BS-73 |
| Draco171942.9+575527.1 | 0.58722 | 20.201 | 19.495 | 20.612 | 0.597 | ab,Bl | BS-147 |
| Draco171931.8+575705.0 | 0.58886 | 20.259 | 19.680 | 20.646 | 0.882 | ab | BS-144 |
| Draco172011.5+575802.9 | 0.58921 | 20.106 | 19.490 | 20.350 | 0.549 | ab,Bl | BS-123 |
| Draco172059.3+580126.6 | 0.58938† | 20.065 | 19.697 | 20.473 | 0.697 | ab | BS-118 |
| Draco171939.9+575753.5 | 0.58939 | 20.209 | 19.636 | 20.609 | 0.728 | ab,Bl | BS-196 |
| Draco171924.8+575847.2 | 0.59003 | 20.219 | 19.628 | 20.652 | 0.806 | ab,Bl | BS-129 |
| Draco171858.2+575256.6 | 0.59182 | 20.041 | 19.510 | 20.419 | 0.778 | ab | BS-104 |
| Draco171953.4+574844.9 | 0.59191 | 20.007 | 19.273 | 20.459 | 0.715 | ab | BS-84 |
| Draco172047.3+575523.5 | 0.59256 | 20.235 | 19.714 | 20.615 | 0.713 | ab | BS-185 |
| Draco172008.9+575623.3 | 0.59285 | 20.166 | 19.671 | 20.510 | 0.724 | ab | BS-126 |
| Draco171902.2+574754.6 | 0.59369† | 20.241 | 19.605 | 20.708 | 0.725 | ab | BS-115 |
| Draco172113.0+575351.1 | 0.59441 | 20.136 | 19.630 | 20.512 | 0.759 | ab | BS-189 |
| Draco171912.0+575437.2 | 0.59466† | 20.151 | 19.588 | 20.785 | 0.576 | ab | BS-109 |
| Draco172107.3+575800.8 | 0.59507 | 20.174 | 19.615 | 20.525 | 0.740 | ab | BS-183 |
| Draco172040.3+575604.5 | 0.59854 | 20.220 | 19.723 | 20.622 | 0.631 | ab | BS-17 |
| Draco171849.6+575356.1 | 0.59875 | 20.147 | 19.566 | 20.536 | 0.658 | ab | BS-64 |

Table 1—Continued

| Name | $P$ (*days*) | $\langle V\rangle$ (mag) | $\langle I\rangle$ (mag) | $\langle B\rangle$ (mag) | $\mathrm{Amp_V}$ (mag) | Type | Comments[a] |
|---|---|---|---|---|---|---|---|
| Draco172015.4+575328.0 | 0.59960 | 20.085 | 19.615 | 20.380 | 0.471 | ab | BS-171 |
| Draco172010.7+574559.1 | 0.60202[†] | 20.258 | 19.721 | 20.813 | 0.459 | ab | BS-88 |
| Draco172102.7+575251.0 | 0.60231 | 20.146 | 19.587 | 20.444 | 0.834 | ab | BS-80 |
| Draco171922.9+574957.9 | 0.60241[†] | 20.160 | 19.308 | 20.785 | 0.445 | ab | BS-137 |
| Draco172116.6+575332.4 | 0.60257 | 20.120 | 19.712 | 20.434 | 0.570 | ab,Bl | BS-26 |
| Draco172057.2+575821.5 | 0.60336 | 20.215 | 19.651 | 20.633 | 0.780 | ab | BS-62 |
| Draco172006.1+580206.8 | 0.60417 | 20.143 | ··· | 20.018 | 0.512 | ab | BS-58 |
| Draco172056.6+575352.9 | 0.60435 | 20.232 | 19.656 | 20.652 | 0.381 | ab,Bl | BS-75 |
| Draco172028.3+575701.2 | 0.60638 | 20.171 | 19.679 | 20.637 | 0.688 | ab | BS-103 |
| Draco172009.2+574538.3 | 0.60730[†] | 20.229 | 19.599 | 20.575 | 0.937 | ab | BS-89 |
| Draco171922.9+575411.8 | 0.60813 | 20.305 | 19.497 | 20.531 | 0.702 | ab | ··· |
| Draco171847.5+575305.3 | 0.60939 | 20.156 | 19.497 | 20.597 | 0.715 | ab | BS-60 |
| Draco172051.2+575148.3 | 0.60998 | 20.075 | 19.420 | 20.575 | 0.497 | ab | BS-133 |
| Draco172046.5+575742.0 | 0.61062 | 20.192 | 19.606 | 20.586 | 0.569 | ab | BS-63 |
| Draco171951.3+574843.6 | 0.61159 | 20.211 | 19.703 | 20.721 | 0.701 | ab | BS-85 |
| Draco172108.7+574746.7 | 0.61525[†] | 20.308 | 19.670 | 20.927 | 0.798 | ab | BS-87 |
| Draco172036.9+575213.1 | 0.61638 | 20.136 | 19.442 | 20.469 | 0.500 | ab | BS-40 |
| Draco172009.3+575438.8 | 0.61688 | 20.024 | 19.458 | 20.433 | 0.474 | ab,Bl | BS-68 |
| Draco172055.1+574335.2 | 0.61701 | 20.306 | 19.675 | 20.850 | 0.915 | ab | ··· |
| Draco172107.0+575942.5 | 0.61720 | 20.077 | 19.383 | 20.324 | 0.740 | ab | BS-95 |
| Draco171835.1+575654.9 | 0.61790 | 20.134 | 19.580 | 20.524 | 0.629 | ab | BS-23 |
| Draco171858.7+575257.0 | 0.61837 | 20.044 | 19.456 | ··· | 0.878 | ab | BS-14 |
| Draco171945.6+575241.0 | 0.61864 | 20.127 | 19.339 | 20.584 | 0.520 | ab | ··· |
| Draco172009.5+575957.7 | 0.61892 | 20.293 | 19.814 | 20.668 | 0.537 | ab | BS-7 |
| Draco171917.6+575332.7 | 0.61954 | 20.146 | 19.591 | 20.546 | 0.668 | ab | BS-101 |
| Draco171838.4+575238.4 | 0.61995 | 20.196 | 19.472 | 20.579 | 0.776 | ab | BS-20 |
| Draco172008.5+574728.6 | 0.62023[†] | 20.003 | 19.510 | 20.533 | 0.690 | ab | BS-49 |
| Draco171851.9+574728.1 | 0.62029 | 20.236 | 19.602 | 20.728 | 0.634 | ab | ··· |
| Draco172026.7+575427.7 | 0.62046 | 20.215 | 19.737 | 20.624 | 0.632 | ab | BS-106 |
| Draco172053.1+575304.1 | 0.62066 | 20.136 | 19.531 | 20.548 | 0.607 | ab | BS-151 |
| Draco172015.7+575417.4 | 0.62150 | 20.767 | 19.622 | 20.703 | 0.859 | ab | BS-71 |
| Draco172040.6+575452.7 | 0.62158 | 20.206 | 19.703 | 20.707 | 0.607 | ab | BS-161 |
| Draco172038.0+575531.2 | 0.62171 | 20.176 | 19.493 | 20.590 | 0.541 | ab | BS-162 |
| Draco172107.1+575409.2 | 0.62505 | 20.183 | 19.396 | 20.428 | 0.952 | ab | BS-70 |
| Draco172017.7+575200.9 | 0.62547 | 19.997 | 19.349 | 20.396 | 0.770 | ab | BS-36 |
| Draco171845.3+575222.5 | 0.62589 | 20.111 | 19.473 | 20.566 | 0.543 | ab | BS-28 |
| Draco172045.1+575128.0 | 0.62606 | 20.201 | 19.522 | 20.591 | 0.499 | ab | BS-164 |

Table 1—Continued

| Name | $P$ ($days$) | $\langle V \rangle$ (mag) | $\langle I \rangle$ (mag) | $\langle B \rangle$ (mag) | $\mathrm{Amp_V}$ (mag) | Type | Comments[a] |
|---|---|---|---|---|---|---|---|
| Draco172029.9+580057.8 | 0.62629 | 20.258 | 19.571 | 20.385 | 0.672 | ab | BS-4 |
| Draco171946.3+574744.4 | 0.62898$^{\dagger}$ | 20.229 | 19.774 | 20.704 | 0.566 | ab | BS-86 |
| Draco172007.1+575949.7 | 0.62923 | 20.205 | 19.503 | 20.468 | 0.599 | ab | BS-98 |
| Draco172053.3+575314.6 | 0.62974 | 20.235 | 20.611 | 20.854 | 0.525 | ab | BS-30 |
| Draco171924.5+575336.3 | 0.63182 | 20.200 | 19.639 | 20.617 | 0.562 | ab | BS-19 |
| Draco172024.2+575141.4 | 0.63182 | 20.400 | 19.853 | 20.643 | 0.614 | ab | BS-132 |
| Draco172050.9+574517.2 | 0.63203$^{\dagger}$ | 20.174 | 19.640 | 20.655 | 0.797 | ab | BS-154 |
| Draco171928.9+574916.6 | 0.63237$^{\dagger}$ | 20.223 | 19.676 | 20.742 | 0.537 | ab | BS-47 |
| Draco172114.1+575435.9 | 0.63392 | 20.193 | 19.660 | 20.586 | 0.524 | ab | BS-128 |
| Draco171942.6+575329.9 | 0.63957 | 20.225 | 19.652 | 20.597 | 0.512 | ab | BS-77 |
| Draco172014.4+574402.3 | 0.64279 | 20.111 | 19.539 | 20.721 | 0.559 | ab | ··· |
| Draco172008.9+575529.7 | 0.64325 | 20.259 | 19.605 | 20.671 | 0.499 | ab,Bl | BS-160 |
| Draco171955.4+574900.5 | 0.64495 | 19.809 | 19.145 | 20.332 | 0.688 | ab | BS-114 |
| Draco172014.9+580146.6 | 0.64701 | 20.313 | 19.036 | 20.569 | 0.720 | ab | BS-3 |
| Draco171858.8+575805.6 | 0.64741$^{\dagger}$ | 20.208 | 19.553 | ··· | 0.436 | ab | BS-66 |
| Draco171905.6+575538.9 | 0.65139 | 20.048 | 19.440 | 20.444 | 0.546 | ab | ··· |
| Draco171945.0+575418.1 | 0.65290$^{\dagger}$ | 20.142 | 19.514 | 20.638 | 0.655 | ab | BS-159 |
| Draco172031.2+575737.5 | 0.65294 | 20.178 | 19.612 | 20.532 | 0.654 | ab | BS-158 |
| Draco172029.3+575808.3 | 0.65345 | 20.232 | 19.646 | 20.643 | 0.200 | ab | ··· |
| Draco172017.1+574641.0 | 0.65431$^{\dagger}$ | 20.293 | 19.685 | 20.798 | 0.736 | ab | BS-140 |
| Draco171929.3+574159.4 | 0.66096 | 20.164 | 19.586 | 20.541 | 0.471 | ab | ··· |
| Draco172013.2+575526.4 | 0.66261 | 20.183 | 19.580 | 20.516 | 0.330 | ab | BS-192 |
| Draco172036.8+574820.6 | 0.66284 | 20.107 | 19.442 | 20.551 | 1.146 | ab | BS-172 |
| Draco171931.8+575927.0 | 0.66353 | 20.117 | 19.420 | 20.568 | 0.666 | ab | ··· |
| Draco171951.3+575321.1 | 0.66449 | 20.193 | 19.536 | 20.636 | 0.686 | ab | BS-127 |
| Draco172025.9+580002.3 | 0.66465 | 20.157 | 19.530 | 20.582 | 0.363 | ab | BS-119 |
| Draco172007.7+580140.5 | 0.66755 | 20.205 | 19.607 | 20.591 | 0.610 | ab | BS-167 |
| Draco171948.8+575657.0 | 0.67368 | 20.096 | 19.499 | 20.449 | 0.505 | ab | BS-188 |
| Draco171928.2+580043.3 | 0.67538 | 20.230 | 19.672 | 20.667 | 0.360 | ab | BS-149 |
| Draco171905.7+575520.1 | 0.67602 | 20.073 | 19.475 | 20.400 | 0.550 | ab | BS-174 |
| Draco172031.4+575303.0 | 0.67633$^{\dagger}$ | 20.095 | 19.471 | 20.497 | 0.402 | ab,Bl | BS-150 |
| Draco172021.6+575431.2 | 0.67650 | ··· | 19.625 | 20.624 | ··· | ab | BS-193 |
| Draco172046.5+574818.9 | 0.67655 | 20.163 | 19.500 | 20.817 | 0.347 | ab | ··· |
| Draco172051.8+575636.0 | 0.67955 | 20.049 | 19.358 | 20.412 | 0.337 | ab | BS-198 |
| Draco172053.5+575704.9 | 0.68168 | 20.157 | 19.596 | 20.547 | 0.585 | ab | BS-125 |
| Draco171944.0+575509.7 | 0.68413 | ··· | 19.442 | ··· | ··· | ab | BS-9 |
| Draco171926.1+574851.4 | 0.68930$^{\dagger}$ | 20.174 | ··· | 20.703 | 0.471 | ab | BS-187 |

Table 1—Continued

| Name | $P$ (*days*) | $\langle V \rangle$ (mag) | $\langle I \rangle$ (mag) | $\langle B \rangle$ (mag) | $\mathrm{Amp_V}$ (mag) | Type | Comments[a] |
|---|---|---|---|---|---|---|---|
| Draco172018.9+580038.0 | 0.69487 | 20.086 | 19.549 | 20.469 | 0.774 | ab | BS-6 |
| Draco172021.1+575219.1 | 0.73201 | 20.024 | 19.459 | 20.497 | 0.319 | ab | BS-81 |
| Draco171944.8+575737.2 | 0.74359 | 20.021 | 19.388 | 20.442 | 0.291 | ab | BS-100 |
| Draco172006.0+575349.4 | 0.76408 | 19.966 | 19.473 | 20.392 | 0.473 | ab | BS-27 |
| Draco172039.0+575732.6 | 0.79062 | 20.006 | 19.381 | 20.403 | 0.188 | ab | ··· |

[a]Names given in Baade & Swope (1961).

*Notes different period from that found by Baade & Swope (1961).

†Notes a star with no period in Baade & Swope (1961).

Table 2. Other Variables in Draco Dwarf Galaxy

| Name | $P$ (*days*) | $\langle V \rangle$ (mag) | $\langle I \rangle$ (mag) | $\langle B \rangle$ (mag) | $\mathrm{Amp_V}$ (mag) | Comments[a] |
|---|---|---|---|---|---|---|
| Draco172017.3+574817.3 | 0.068,0.073,0.079 | 21.985 | 21.468 | 22.033 | 0.873 | SX Phe |
| Draco171906.2+574120.9 | 0.2435 | 19.645 | 18.058 | 20.751 | 0.266 | Ecl. Binary |
| Draco171906.4+574948.2 | 0.59229* | 18.846 | 18.368 | 19.267 | 0.877 | Ceph, BS-134 |
| Draco172017.8+575708.1 | 0.90085 | 19.204 | 18.573 | 19.640 | 0.679 | Ceph, BS-141 |
| Draco171934.5+575849.6 | 0.93644 | 19.043 | 18.439 | 19.597 | 0.888 | Ceph, BS-157 |
| Draco171918.4+575245.7 | 1.58993 | 18.123 | 17.501 | 18.542 | 0.460 | Ceph, BS-194 |
| Draco171855.0+574733.1 | 5.1150 | 17.707 | 16.586 | 18.655 | 0.101 | |
| Draco172037.4+575913.0 | ··· | 17.051 | 15.584 | 18.315 | ··· | |
| Draco172032.9+575144.2 | ··· | 16.977 | 15.418 | 18.430 | ··· | |
| Draco172040.2+575733.0 | ··· | 16.488 | 14.927 | 17.893 | ··· | |
| Draco172106.3+575410.9 | ··· | 16.658 | 19.396 | 20.428 | ··· | |
| Draco171929.5+575825.6 | ··· | 16.855 | 15.279 | 18.173 | ··· | |
| Draco171922.5+575404.2 | ··· | 17.326 | 15.921 | 18.932 | ··· | |
| Draco171935.5+575846.4 | ··· | 17.161 | 15.622 | 18.509 | ··· | |
| Draco171945.8+575626.1 | ··· | 19.548 | 18.832 | 19.783 | ··· | BS-203 |
| Draco171952.2+575909.3 | ··· | 17.487 | 16.078 | 18.690 | ··· | |
| Draco172120.1+580118.7 | ··· | 16.102 | 15.239 | 16.866 | ··· | |

[a]Type of variable and name given in Baade & Swope (1961).

*Notes different period from that found by Baade & Swope (1961).